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# AN ATTEMPT TO CORRELATE SMOKE FROM EVERGLADES FIRES WITH URBAN SOUTH FLORIDA AIR QUALITY

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## INTRODUCTION

South Florida can be thought of as an 11 million-acre saucer with the population concentrated along the rim, while the lower, virtually uninhabited interior south of Lake Okeechobee contains a vast expanse of sawgrass called the Everglades and a large swamp dominated by cypress, aptly called the Big Cypress Swamp. These lower areas are underlain with organic soils and remain flooded most of the year.

Abundant water, long sunny days, and warm temperatures combine to produce lush vegetative growth during the summer wet season. However, this fuel complex becomes progressively more flammable during the November to May dry season as surface waters recede. The soils themselves become dry enough to burn during drought years. This is exactly what happened when a series of droughts occurred in the 1970's. Wildfires burned approximately 3 million acres between 1969 and 1975. In 1974, 12 percent of all protected land burned by wildfire in the United States was in south Florida. In 1975 the figure was 13 percent. Extensive volumes of organic soil were consumed. Some fires lingered for months until finally extinguished by summer rains and a rising water table. During April 1971, visibilities were at times reduced to less than 1/4 mile in the Miami area and the Community Research Branch of HEW (no date) stated that the acute air pollution episode was the result of Everglades fires. Smoke from these fires disrupted both air (Williams 1976) and highway traffic. Hospital admissions for respiratory ailments increased and tourism was adversely affected.

In addition to the wildfire acreage, 1.45 million acres are burned by prescription in south Florida each year. Objectives of these intentional burns include wildlife habitat improvement, range management, ecotype maintenance, control of undersirable species, reduction of wildfire hazard, land clearing, and agricultural improvement. The result is a conflict of interest between land managers and resource users on the one hand and people with respiratory ailments and those who simply want clear skies on the other.

The impact of wildland fire upon smoke-sensitive areas on the lower Florida peninsula is unknown. Extensive fires in interior south Florida often coincide with periods of reduced visibility from haze that looks and smells like wildfire smoke. I attempted to correlate this reduced visibility, as measured by total suspended particulate (TSP), to wildfires using both source and receptor modeling approaches.

## METHODS AND RESULTS

The source modeling approach looks at the pollution source (in our case, a wildfire) and (1) determines emission rates for the time in question from various fuel and fire characteristics, (2) estimates transport and dispersion from meteorological conditions, and (3) predicts the amount of a pollutant that will reach a given receptor. Receptor modeling, on the other hand, starts with the target and (1) measures the ambient concentration of TSP at a given receptor site, (2) physically and/or chemically characterizes the sample, (3) identifies sample properties which are unique to specific sources, and (4) assigns characterized fractions to given sources.

Archived data from the state and local air monitoring network, consisting of approximately 85 south Florida locations (fig. 1), was obtained for the 3 years 1974-76. This period includes the bad fire years of 1974 and 1975. It should be noted that sampling stations were both added and dropped during the study period and that virtually no stations exist in the interior where smoke concentrations were highest

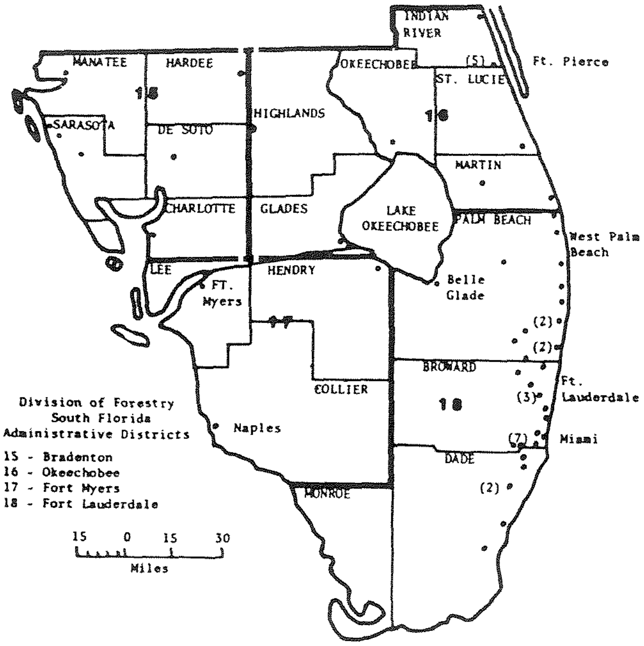


Figure 1.--South Florida counties, selected cities, and the location of air quality monitoring sites. Numbers in parentheses indicate multiple stations in urban areas. (After Kauper, 1978).

Impaired air quality was assumed if a 24-hour TSP value exceeded 100 $\mu g/m^3$ even though this value is well below both the Federal Primary 24-hour Standard of 260 $\mu g/m^3$ and Secondary Standard of 150 $\mu g/m^3$.

Air quality impact for this paper was quantified on the basis of Prevention of Significant Deterioration (PSD) legislation as discussed by Paulson, Hough, and Baker (1978). PSD legislation partitions all land into 1 of 3 classes. Class I areas are the most restrictive and include Everglades National Park in south Florida. The maximum allowable 24-hour increase over the baseline concentration in Class I areas is 10 $\mu g/m^3$. The Big Cypress National Preserve is a Class II area. For Class II areas, the maximum allowable 24-hour increase over baseline is 37 $\mu g/m^3$. It was postulated that if values exceeded these maximums at the urban sampler sites, they could also exceed them at these nearby Class I and II areas where much of the smoke originated.

## Source Modeling Approach

Analyses of historical TSP and meteorological data for the study period were contracted out; the summary presented here is extracted from the final report of this contractor (Kauper 1978).

The number of times the Federal 24-hour Primary Standard of 260 $\mu g/m^3$ and Secondary Standard of 150 $\mu g/m^3$ were violated, along with the total number of observations by year are given in table 1. Table 1 shows that 1974 was the worst of the 3 years in terms of particulate pollution as measured by TSP.

Table 1.--Number of 24-hour TSP occurrences above standards in southern Florida (After Kauper 1978).

| Year | Primary 260 $\mu g/m^3$ | Secondary 150 $\mu g/m^3$ | Total Observations |
|---|---|---|---|
| 1974 | 8 | 53 | 2523 |
| 1975 | 5 | 21 | 2749 |
| 1976 | 0 | 7 | 3081 |

All TSP values above 100 $\mu g/m^3$ were identified during the 3-year study period. Additional analyses were performed: (1) in all cases where at least two locations recorded values above this threshold on a given day and (2) in every case where TSP exceeded 350 $\mu g/m^3$. Some 200 of the more than 350 date-site combinations identified met these requirements.

Pertinent meteorological data were obtained for the 59 days on which these 200 readings occurred. The days were than grouped on the basis of visibility and Kauper's 24-hour resultant wind computations. A representative sample comprised of 16 days was selected from these groups, and synoptic weather patterns were examined, mixing heights calculated, and 3-hour streamline maps prepared. Wind trajectories, going backward in time, were constructed four times during the 24-hour sampling period for each location with a TSP value above 100 $\mu g/m^3$ on each of these 16 days. These trajectories, based on the 3-hour streamline maps, show the hypothetical paths taken by air parcels arriving at the sampler site at 6-hour intervals. An example is presented in figure 2.

Kauper's (1978) comparison of surface weather charts on study days indicated smoke was most likely to impact east coast urban areas in lower Florida when an east-west oriented front was situated south of latitude 35°N (north Georgia) producing a westerly flow, early morning inversions, and rather deep mixing later in the day in south Florida. His analysis showed these conditions prevail 7-9 percent of the time with most occurrences during January, February, and May.

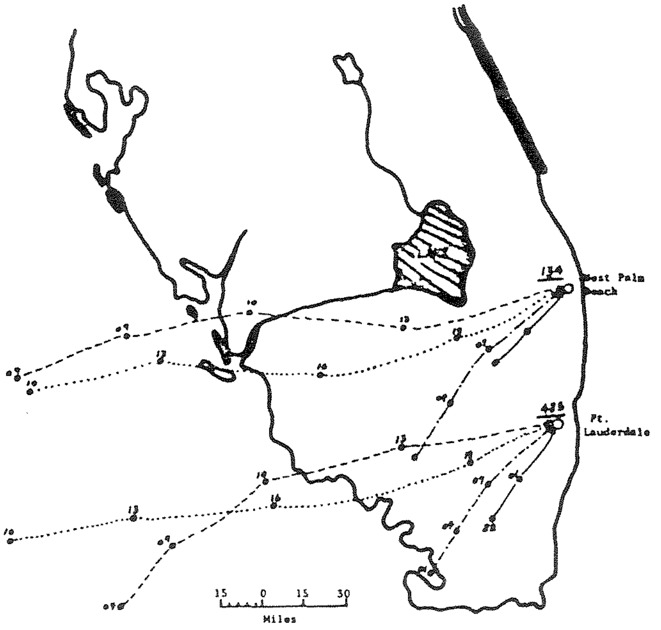


Figure 2.--Wind trajectories that show the paths taken by air parcels arriving over the sampler site on 3/30/74 at: 0400 EST ———, 1000 EST —·—·—·—·, 1600 EST -----, 2200 EST ·····. Underlined numbers are recorded TSP values in $\mu g/m^3$. (After Kauper 1978).

A sea breeze developed along the east coast on each of these days. In fact, a sea breeze was noted on all study days with resultant windspeeds under 10 mph except those associated with the passage of a cold front--in which case winds were northerly.

High winds were quite prevalent on high TSP days. Since days in this category that were studied were not conducive to the accumulation of pollutants, the high TSP values were assumed to be caused by the wind picking up increased amounts of surface dust.

Data pertaining to both wild and prescribed fires for the years 1974-76 were obtained from the Florida Division of Forestry (FDOF). Archived wildfire data include a detailed report of each fire, whereas retrievable prescribed fire summaries do not include specific locations or dates. Statistics on wildfire and prescribed fire (which includes land clearing and agricultural burns) are presented in table 2. Table 3 shows days on which more than 5,000 acres were burning in any one FDOF District. The final column indicates dates that correspond to high TSP days, and stars on dates in the first column denote days that fall either on, or the day before, one of the 16 special study days.

To examine fire activity on the 59 days used by Kauper (1978) and on the day prior to each of these sample days, I searched the records for wildfires meeting the following criteria:

(A) All organic soil fires and all other fires at least 1 acre in size, within 6 miles of the closest sampler recording a high TSP value.

(B) All fires with acreage exceeding the mileage to the closest sampler recording a high TSP value when this distance is between 7 and 25 miles.

(C) All fires 26 to 50 miles away where the acreage burned was at least twice the distance in miles.

(D) All instances where total fire acreage exceeded 500 acres and the fires originated 51 to 100 miles from a sampler with a high reading on that date or on the next day.

(E) All instances where total fire acreage exceeded 1,000 acres for distances over 100 miles away within FDOF Districts 15-18 (see fig. 1 for District map). On 24 of the 59 sample days, no fires fell in any of the 5 categories. On 26 sample days (or day prior), fires occurred in A and/or B categories and on the remaining 9 days, fires occurred in categories C-E. I also compared the January - June 1974 TSP record for the 12-station network in Broward County (Ft. Lauderdale) against the 5 categories of fire activity to investigate days when TSP was below the 100 $\mu g/m^3$ threshold value. Again, no clear-cut pattern emerged. At least one station exceeded 100 $\mu g/m^3$ during 23 of the 30 sample days, but no fires were burning on 20 of the 30 days (or day prior). Furthermore, on 3 of the 7 days when all TSP values were below 100 $\mu g/m^3$, category B Fires occurred. One of these fires started 9 miles southeast of the closest sampler, reached 900 acres in size, and consumed organic soil.

Next, I determined the particulate mass concentration values that would be predicted by operationally available smoke management aids for each fire at both nearby and downwind sampler locations for the same 16 days used by Kauper (1978).

Meteorological information on the 8 sample dates associated with fires that fit categories A-E along with the archived fire information for fires on those days was inputed into SMOGO, a computer program that predicts plume centerline particulate mass concentrations at various

Table 2.--Selected South Florida Fire Statistics.

| Month | District 15 Wildfire Acreage | | | District 16 Wildfire Acreage | | | District 17 Wildfire Acreage | | | District 18 Wildfire Acreage | | | Totals by Month |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 74 | 75 | 76 | 74 | 75 | 76 | 74 | 75 | 76 | 74 | 75 | 76 | |
| Jan. | 10,818 | 2,110 | 834 | 1,228 | 1,962 | 3,611 | 2,679 | 1,254 | 6,396 | 2,420 | 978 | 1,949 | 36,249 |
| Feb. | 5,311 | 2,443 | 1,052 | 2,418 | 1,642 | 5,880 | 23,381 | 1,401 | 4,697 | 6,752 | 581 | 2,281 | 57,839 |
| Mar. | 10,402 | 4,638 | 1,193 | 6,433 | 3,802 | 2,297 | 55,489 | 4,010 | 871 | 11,166 | 29,826 | 2,303 | 132,430 |
| Apr. | 13,312 | 2,494 | 1,181 | 19,722 | 8,354 | 3,237 | 93,529 | 74,519 | 1,721 | 18,610 | 28,600 | 2,040 | 267,319 |
| May | 6,791 | 2,336 | 972 | 1,555 | 4,068 | 516 | 5,715 | 1,775 | 1,291 | 2,377 | 4,477 | 152 | 32,025 |
| June | 2,449 | 1,286 | 591 | 1,096 | 947 | 29 | 542 | 2,155 | 202 | 1,844 | 122 | 16 | 11,279 |
| July | 66 | 59 | 568 | 56 | 414 | 961 | 33 | 500 | 513 | 51 | 65 | 221 | 3,507 |
| Aug. | 118 | 126 | 160 | 100 | 102 | 246 | 25 | 480 | 70 | 30 | 184 | 4 | 1,645 |
| Sept. | 181 | 101 | 44 | 53 | 14 | 159 | 43 | 8 | 111 | 5 | 51 | 21 | 791 |
| Oct. | 47 | 5 | 47 | 627 | 163 | 551 | 354 | 93 | 23 | 184 | 60 | 357 | 2,511 |
| Nov. | 490 | 53 | 21 | 350 | 425 | 368 | 194 | 820 | 284 | 232 | 675 | 203 | 4,115 |
| Dec. | 796 | 254 | 331 | 1,034 | 2.758 | 105 | 1,156 | 393 | 944 | 2,221 | 2,212 | 474 | 12,678 |
| Totals by Year | 50,781 | 15,905 | 6,994 | 34,672 | 24,651 | 17,960 | 183,140 | 87,408 | 17,123 | 45,892 | 67,831 | 10,021 | |
| Prescribed Fire Acreage | 705,061 | 497,842 | 473,037 | 220,818 | 492,702 | 301,229 | 346,051 | 447,470 | 675,845 | 24,885 | 143,397 | 29,867 | |

Table 3.--Dates on which more than 5,000 acres were burning by District.

| Date | District | Acreage on Fire | No. of High TSP Days ( $\geq 100\ \mu g/m^3$) |
|---|---|---|---|
| 1/25/74 | 15 | 5,500 | |
| 2/17-19/74 * | 17 | 9,340-12,685 | 1 |
| 3/9/74 | 17 | 38,460 | 1 |
| 3/30/74 * | 17 | 5,190 | 1 |
| 4/6/74 | 17 | 20,711 | |
| 4/8/74 | 17 | 13,400 | |
| 4/11-14/74 | 18 | 8,000-8,900 | 1 |
| 4/14/74 | 17 | 5,615 | |
| 4/21/74 | 17 | 12,399 | |
| 4/28/74 * | 16 | 13,148 | |
| 4/30/74 | 17 | 20,355 | 1 |
| 3/28-4/4/75 | 18 | 27,000-27,745 | 3 |
| 4/4-12/75 | 17 | 22,455-63,687 | 3 |
| 4/24-5/7/75 * | 18 | 22,000-26,000 | 2 |

*Indicates days that fall either on, or the day before, one of the 16 special study days.

downwind distances as described in the Southern Forestry Smoke Management Guidebook (SFFL Staff 1976). Although not designed to handle complex wind flow situations such as the sea breeze, SMOGO was the best model available. An emission factor of 20 lbs/ton was used for sawgrass and wet prairie fuels (Ward 1979). It was assumed these fuels were all burned during the advancing front fire stage. A value of 25 lbs/ton was assigned to the 60 percent of the available fuel in the palmetto-gallberry fuel complex estimated to be consumed during the advancing fire front, while the 40 percent that burned during the residual stage was given an emission factor of 125 lbs/ton (SFFL Staff 1976). Recent work, however, suggests this 60/40 ratio is not correct and that particulate matter emission factors are, instead, a function of fire intensity (Ward, Clements, and Nelson 1980). Length of fired line and rate of spread inputs were determined using acreage and fire duration data along with published perimeter to acreage and rate of spread to perimeter relationships (Cargill 1970; Forbes 1955).

Fires with organic soil involvement present a special problem because much of the total area is often on fire at the same time. An "effective" line source rate in μg/meter-sec for a uniform area source was determined for these fires using the formula

$$ER = \frac{\sqrt{A} \times T \times EF \times 1980}{D}$$

where ER = emission rate (source strength) in μg/meter-sec

A = total area burned in acres

T = available fuel (fuel consumed) in tons/acre

EF = emission factor in lbs of particulate formed/ton of fuel consumed

1980 = a constant that converts English units to metric

D = fire duration (burnout time) in hours.

Organic soil emission factors vary from less than 1 lb/ton in well established deep burning fires under a heavy ash layer to over 100 lbs/ton for actively burning surface soils (McMahon, Wade, and Tsoukalas 1980). Likewise, the amount consumed depends upon the depth of the burn which is primarily a function of the water table level. Approximately 34 tons/acre of soil are consumed per inch of depth. Emission rates were determined for each organic soil fire, the input values determined by the date, and age and location of the fire. Heat release from these organic soil fires was assumed to be low so they were considered to be burning without convective lift.

Nineteen fires fitting categories A-E occurred on 7 of the 16 study days. Predicted particulate mass concentrations at the hi-vol monitoring sites were calculated for these fires. Individual predictions ranged from 0 to 1725 $\mu g/m^3$. When resultant wind directions were considered, however, only 3 fires on 2 days (3/30/74 and 5/2/74) appeared capable of impacting the samplers. The importance of wind direction is illustrated on a 3,000-acre wildfire that started on 3/27/74 and was mopped up on 4/1/74. All 12 Broward County air quality monitoring sites collected TSP samples on 3/30/74. Those close to the resultant wind direction all exceeded 100 $\mu g/m^3$. The closest station, 11 miles ENE of the fire origin, recorded a TSP value of 425 against a predicted value of 370 $\mu g/m^3$. However, samplers located just a few miles off the reestablished plume centerline did not have elevated readings. For example, one station 10 miles east of the fire origin and 5 miles south of the above station had a recorded value of 68 $\mu g/m^3$ while the predicted value (ignoring wind direction) was 390 $\mu g/m^3$.

## Receptor Modeling Approach

This procedure assigns the mass of the chemical or physical compounds of each type of source collected on the hi-vol filter to that source. To achieve meaningful results, however, unique signature compounds for each source must be known. This approach has been successful in characterizing the aerosol for a number of locations, including southern California (Gartrell and Friedlander 1975), Phoenix, Arizona (Craf, Snow, and Draftz 1977), and Portland, Oregon (Cooper, Watson, and Huntzicker 1979). Results of the Portland study (Lyons et al. 1979) suggest the potassium/iron ratio is a good signature compound for slash fires, but I had to find a parameter that was available from the limited historical data base. Particulate matter produced by the incomplete combustion of forest fuels is somewhat unique in that it contains large amounts of organic compounds which are soluble in benzene. This is known as the Benze Soluble Organic (BSO) fraction of particulate matter. The BSO fraction of particulate matter from wildfire smoke ranges from 40 to 75 percent and averages about 55 percent (Ryan and McMahon 1976). For organic soil fires, the BSO fraction approaches 100 percent. Thus, on those days with a high TSP value and low BSO value, it can be concluded that forest fires, and other sources of incomplete combustion, were not a major particulate pollutant at that site. Dade was the only County with archived BSO data. I used a worst case approach and assumed all BSO above the 3-year mean + 1 standard deviation (4.37 $\mu g/m^3$ + 1.33) was due to wildfires and that 55 percent of the wildfire TSP at a receptor was in the form of BSO. I then calculated the total TSP attributable to wildfire at each date-location combustion and compared it against the PSD maximum 24-hour allowable increments of 10 and 37 $\mu g/m^3$. Of this 158.3 $\mu g/m^3$ total, $15.1 - 5.7 \div .55 =$ 17 $\mu g/m^3$ can be attributed to wildfires. Fifty-two cases occurring on 24 days exceeded the 24-hour PSD Class I maximum of 10 $\mu g/m^3$. Fires occurred on 11 of the 24 days--all within 25 miles of the closest sampler. The worst case approach is an excellent tool providing the results are negative. However, when events seem to be correlated, interpretation becomes less clearcut. For example, BSO is a product of all incomplete combustion sources which also includes vehicles, burning garbage dumps, and structural fires. Thus, it cannot be said with any degree of certainty, that wildfires caused the high BSO found on the above 11 days.

The opportunity to compare the receptor modeling approach with the retrospective trajectory method occurred on only 1 date--5/2/74. SMOGO predicted a loading of 25 $\mu g/m^3$ while the BSO analysis showed 17 $\mu g/m^3$ was due to fire. This is fairly good agreement, especially in light of the assumptions made, but not much can be said based on a sample of one.

## Discussion and Summary

This exercise points up many of the shortcomings of these approaches. Some are connected with the samplers themselves. For example, the sampler sites may be poorly located for the study, and the samplers are run 24 hours at a time so that both short-term and intermittant sources may be masked. But the biggest handicap is the fact that samples are routinely collected only every sixth day.

Limitations unique to the source model approach are associated with errors involved in using archived fire data to reconstruct emission production and other needed source data. Further, available transport and dispersion models may be off by a factor of 2 or more (Pasquill 1974)--particularly so in the case at hand since the models were not designed to account for sea breeze influences. Normally, this sea breeze provides good smoke dispersion, but extensive fire activity can overload the system, thus recycling smoke back in over the coast. The nighttime land breeze, in some cases, may also carry interior ground-level smoke toward urban coastal areas. Similar phenomena have been reported for the Los Angeles basin (Edinger et al. 1972) and the lake breeze system on Lake Michigan (Lyons and Olsson 1972).

In spite of these limitations, the source modeling approach has a certain appeal because if a relationship can be established, a bridge between the source and receptor is provided, allowing one to follow the path the pollutants took to arrive at the target.

The receptor modeling approach does not suffer from the above limitations. This approach is relatively new and signature compounds are still being identified for a variety of sources. Individual exploratory chemical analyses are expensive, but, as the methodology evolves, costs should drop. In the meantime, however, archived operational data will remain very limited. The one major shortcoming of the chemical mass balance method is that although it can show exactly what and how much actually arrived at a target, it cannot differentiate between multiple sources of the same type. Thus, if several fires were burning at the same time, this method could not be used to determine whether just one or all the fires were involved, or to apportion the total among fires. But, it does answer the most important question--what source contributed to the concentrations measured at the target site.

One solution would be to use a combination of methods; first, run SMOGO using simple estimates of fire and wind data. If predicted downwind concentrations are large enough, next run a chemical mass balance; then, if fire was found to be a contributing factor and more than one fire was involved, proceed with a retrospective trajectory analysis using more exact estimates. Ward and Elliott (1976) set up their own sampler network and were able to correlate acres of open burning (silvicultural and agricultural use of fire and wildfire) to BSO concentration but not to suspended particulate. On the other hand, Williams[1/], also using archived data, failed to correlate TSP readings to nearby prescribed fire activity in the Savannah, Georgia, area. Perhaps the source modeling approach would meet with more success on sites further inland where the sea breeze is not a problem or, more importantly, wherever sampling is more frequent than every sixth day. For example, given day and night emission rate estimates from a large area and daily TSP values, Lavdas (1980) was able to relate TSP to tons of fuel consumed.

In any event, the challenge is here. Facts are urgently needed. Our ability to provide meaningful input to emotionally charged issues such as the air quality impacts of wildland fires will, in large part, determine whether these issues can be rationally discussed, or whether decisions will be based on subjective criteria.

## ACKNOWLEDGMENTS

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